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## TASK OBJECTIVES

The objective of the first half of this years' effort was to complete the analyses and evaluation of vegetation indices with respect to their sensitivity to detect changes and/or differences in vegetation amounts. Some criteria for sensitivity evaluation and noise assessment were established.  Increased attention was placed on determining error and uncertainty analyses within the realm of MODIS instrument characterization.   This was done in preparation for the Algorithm Theoretical Basis Document.  Validation criteria have been drawn up and improved estimates of vegetation assessment have been documented.  As the final form of the vegetation index equation takes form, consideration is now given into how this level 2 product will be spatially and temporally composited into the level 3 vegetation product, with primary attention given to the "view" angle problem of surface anisotropy.


## WORK ACCOMPLISHED

In January the first MODIS vegetation index manuscript was prepared, entitled "Development of vegetation and soil indices for MODIS-EOS",  by Huete, A.R., Justice, C., and Liu, H.  This was submitted to Remote Sensing of Environment journal as part of a special issue from the "Soils and Vegetation Remote Sensing" workshop held in Tempe, Arizona, January 6-8, 1993.   This manuscript outlined the current status of vegetation indices for at-launch and post-launch MODIS products.  The structure of the normalized difference vegetation index (NDVI) for vegetation assessment and monitoring was basically accepted but with suggested modifications to the equation to "calibrate" for canopy background and atmospheric sources of noise and uncertainty.  These calibration coefficients have reduced the error in the NDVI from 30% green cover equivalent uncertainty to less than 10% uncertainty under representative

but diverse soil and atmospheric conditions.

A second and third vegetation index (VI) manusucript are in preparation and ready for submission.  In the second paper, a sensitivity analyses was performed on a core set of 6 VI's ranging from the NDVI and SAVI to the ARVI and SARVI (Fig. 1) using both empirical data sets and canopy radiant transfer simulations (SAIL model).  Both data sets included a LOWTRAN atmospheric simulation.  Some of the results of this analyses are included in the "Data Interpretation" section below.  The third manuscript addresses the feedback problem whereby one cannot necessarily remove one source of noise, such as atmosphere, without aggravating a second noise term, like soils.  As a result a feedback scheme is needed to stabilize the vegetation index equation and further decrease uncertainties due to soil and atmosphere, while keeping the equation sensitive to the vegetation signal.

The work accomplished includes field-related activities, data processing and image analyses, modeling work, and canopy and atmospheric simulations.


## 1.  FIELD ACTIVITIES

### 1.1.  PORTUGAL:

From June 23 to July 1, field research was conducted in northern Portugal in the Maritime Pine forests and Oak Woodland biomes.  A collaborative project was established with Dr. Jose Pereira of the Universidade Tecnica de Lisboa to obtain high resolution spectra of several Mediterranean vegetated biomes from the Pine forests in northern Portugal to the Oak woodlands and shrub biomes in the more arid, southern portions of the country.  These biome types are represented throughout the Iberian peninsula, which include large portions of Spain.

A helicopter was reserved to obtain reflectance spectra from over these canopies with a Spectron SE 590 and an Exotech Model 100 radiometer mounted on the helicopter.  In addition, ground-based radiometric measurements were obtained with the goal of obtaining

canopy understory reflectances as well as canopy transmittance spectra. These measurements will be used in a model to better describe spectral interactions between vegetation and background, whether the background is soil, litter, or another layer of herbaceous or woody vegetation. These data will also be used to validate the vegetation index products for MODIS as to their ability to remain sensitive to the vegetation signal and not be influenced by background.

A second objective of the field research was to further explore the use of mixture modeling to determine what is underneath tree canopies. This has potential uses in soil discrimination, litter assessment, carbon cycling, and fuelwood loadings for fire monitoring. The use of temporal mixture modeling will also be explored to determine if the undergrowth vegetation signal can be separated from the overlying tree canopy signal, based on differing temporal patterns (phenological).

1.2  NIGER-HAPEX:

Wim van Leeuwen, a Ph.D. student, attended the Toulouse, France meeting regarding HAPEX-Sahel activities, May 11-13. Wim summarized, documented, and presented the ground radiometric data that was collected.

Wim will be utilizing the ground, air, and satellite data from HAPEX-Niger to further vegetation index work for MODIS. Of special interest are the ASAS flights onboard the C-130 that were carried out during the 8-week Special Observation Period (SOP), August 17 to October 9. The ASAS flights covered the grassland, grass-shrub mixture, millet, and degraded shrubland sub-sites within the 3 major supersites. We will rely on this data set, coupled with the ground data, for VI validation and coupling to plant biophysical parameters. The Niger data sets, coupled with those at Walnut Gulch, Arizona, will be used to study VI sensitivity at the lowest (sparse vegetation) boundary condition as well as to determine how well one may estimate biophysical plant parameters under "global" conditions (i.e., separate continents). These arid zones are crucial in that they are also fairly responsive to climatic fluctuations.

A manuscript was prepared entitled "Optical dynamics and vegetation index sensitivity to biomass and plant cover in arid shrub savannnah sites in Niger" by W.J.D. van Leeuwen, A.R. Huete, J. Duncan, and J. Franklin. This paper concerns the Niger activities of 1991 at the Ouallum site and has been re-submitted following minor revision to the journal 'Agriculture and Forest Meteorology'.

1.3 CHINA TEST SITE SELECTION

A trip was made to the Laboratory of Resources and Environment System (LREIS) in Beijing, China from May 19 to June 3 at the invitation of the Institute of Remote Sensing and Institute of Geography within the Chinese Academy of Sciences. The purpose was to explore the development of remote sensing methodologies for the study of land cover change in China. One week was spent in Beijing with me giving 3 days of lectures on Remote Sensing and Global Change topics. Harold Oseroff provided vugraphs of the MODIS sensor for use on this trip. The second week consisted of a field trip into the mountainous portions in western Hunan Province to visit an ecological research site. My hosts included Ms. Zhang Qijuan and Mr. Liu Jian of the Bureau for Coordination Development of Nature and Society within the Chinese Academy of Sciences and Dr. Wu Binfang of the Institute of Geography.

The overall purpose of the Chinese trip was to learn about the Chinese Ecological Research Network (CERN) and how their various ecological sites can be used for remote sensing studies of land cover and land cover change analyses as well as to study the use of vegetation index equations over different types of biomes. There are currently 53 CERN sites with research stations.

China is changing fast, with rapid economic development and future environmental changes. Along with heavy population pressures, there is heavy exploitation of land with accompanying problems associated with erosion, pollution, and acid rain. As a result, there is rapid and widespread changes in surface albedo, and the energy and hydrologic balances of entire provinces. This provides an excellent opportunity in the MODLAND's effort to characterize and monitor the earth's land cover and to aid in the development of methodologies and algorithms to map the

major land cover classes of the earth.   In addition to the land cover algorithm product, the China CERN sites also can aid in the land cover "change" algorithm in order to study how the earth's surface is changing and what impacts such changes have on land surface hydrologic and energy fluxes.

As a result of the 2 weeks in China, a collaborative effort was proposed with the Bureau for Coordination Development of Nature and Society within the Chinese Academy of Sciences (CAS) to utilize satellite imagery over China to study land cover and land cover change.  In agreement with CAS, 12 initial CERN test sites were selected (Table 1) to encompass the diverse range of China's climatic, land use, and geomorphological zones.  The list of sites include wetlands, temperate to tropical forests, grasslands, snow covered areas, agriculture, and desert. These sites are equipped with ecological and meteorological ground stations and existing ground- based data and information programs (historical and current), which offer the opportunity to develop and analyze methods for the study of land cover change with remotely-sensed data.

The potential collaborative nature of the proposed project is similar to that established with MODIS and the Long Term Ecological Research Network (LTER) within the U.S. and includes:

1.  The U.S. side would process and provide satellite imagery over the 12 China sites, including 1 km NOAA-AVHRR "vegetation index" images,  available Landsat TM imagery and MSS imagery.   The number of TM scenes per year and per site have yet to be determined, but would ideally include 1 TM image per site per year and over certain sensitive sites, 4 TM images in one given year, pending sufficient funding.

2.  The U.S. side would coordinate any "ground-based" optical measurement campaigns with field radiometers, sun photometers, and GPS (geo-positioning system) units.  Such campaigns would only be conducted if necessary for the interpretation of the satellite imagery.

3. Additional members of the MODIS Science Team would be invited to participate in this effort at any level. This includes exchanges involving Chinese students and/or scientists.

As part of the collaboration, CAS has agreed to support the project with the following:

1. CAS would provide a preliminary classification of Landsat TM imagery into land cover classes. Part of this effort will involve 'visual' inspection and verification of the land cover units.

2. CAS would collect and provide digitized GIS data layers over each study site, including soil, geology, vegetation, climate, land-use, and topography maps.

3. CAS would provide additional 'ground' meteorological and biophysical soil and plant information such as rainfall data, soil moisture, plant biomass, etc. Much of this data will be measured and collected by several Institutes under the auspices of the Chinese Ecological Research Network (CERN).

4. CAS would document and verify any 'on-site' changes in land cover detected by the satellite measurement program. This will serve to validate the land cover change algorithm and methodology.

If there is sufficient interest, presentation of such collaborative projects and results would be made at the International Symposium on Global Change to be held in Beijing in 1995. Special topical sessions will be held on remote sensing and global change resulting from this project.

Chris Justice has requested some TM scenes over these CERN sites, with priority to #'s 7, 2, 3, 8, and 4 in Table 1 below.

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Table 1.            CHINA CERN SITES
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| SITE | DESCRIPTION | STATION NAME | LOCATION | |
|------|-------------|--------------|----------|----|
| | | | NL | EL |
| 1 | wetland | Hailun Experimental Station of Agricultural Ecology | 47o26' | 126o38' |
| 2 | mixed forest | Changbaishan Experimental Station of forest Ecology | 42o24' | 128o06' |
| 3 | grassland | Inner Mongolia Experimental Station of Grassland Ecosystem | 43o26' | 116o4' |
| 4 | transition zone | Ansai Comprehensive Experimental Station of soil & water Conservation | 36o41' | 109o13' |
| 5 | farmland(wheat) | Yucheng Comprehensive Experimental station | 36o57' | 116o36' |
| 6 | rice field | Taoyuan Experimental Station of Agricultural Ecology | 28o55' | 111o29' |
| 7 | deciduous forest | Huitong Experimental Station of Subtropical Forest Ecosystem | 26o48' | 109o30' |
| 8 | tropical forest | Xishuangbanna Experimental Station of Tropical Ecology | 23o00' | 105o00' |
| 9 | desert monitoring site | Shapotou Experimental Station of Desert | 37o27' | 104o57' |

| 10 | grassland | Fukang Experimental Station of Desert Ecology | 44o10' 87o55' |
| 11 | snow cover | Linze Experimental Station of Desert | 39o20' 100o9' |
| 12 | plantation/ Econ. develop | Hainan Experimental Station of Tropical Marine Biology | 18o13' 109o28' |

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## 2.  DATA PROCESSING

### 2.1  WALNUT GULCH, ASAS DATA:

Hui Qing Liu, research specialist, continued to process 1991 ASAS imagery (dry and wet season) over the Walnut Gulch Experimental Watershed, focussing on the Kendall (semi-desert grassland) and San Pedro (riparian vegetation and mesquite-bosque) multiple view images.  A percent error,  and vegetation equivalent noise (V.E.N.%) analyses were made at the Kendall site to analyze vegetation index sensitivities and noise.  North and south slope pixel values on 10% slopes were extracted. The ASAS imagery allowed us to simulate the first 4 MODIS bands over a range of viewing conditions, as well as allow us to perform and test mixture modeling schemes for land cover analyses and soil-plant-litter component extraction.

The on-site, measured optical depth data over the Kendall site were provided to us by the Optical Sciences Department, Univ. of Arizona.  The atmospheric data were derived from Langley plots and were computed for the MODIS bands.  Work is now proceeding on atmospheric correction of the ASAS scenes.  Also, atmospheric correction is being computed via radiant transfer programs, including 5S and LOWTRAN.

## 2.2 Walnut Gulch, Thematic Mapper Data:

Karim Batchily, research specialist, is working on the 1992 Landsat TM imagery acquired over the Walnut Gulch site from April through November. Eight good (cloudless over the study sites) scenes have been analyzed and pixel windows extracted. The objective is to analyze the multitemporal behavior of various vegetation indices across the watershed from desert shrubland sites to shrub-grass mixed sites, grassland, mesquite bosque, and cottonwood riparian areas. This data is concurrent with precipitation data and weekly biomass and LAI data. The TM results were also matched with ground and airplane based exotech data. Optical depth measurements were made concurrently and the radiant transfer code/ processing to utilize this data still need to be completed. Providing this image data set to the MODIS Land Team for MODIS multitemporal simulation remains as a future task.

## 2.3 AVHRR STUDY SITES:

Qi Jiaguo, Ph.D. candidate, performed some compositing of AVHRR data over 5 test sites extracted and compiled by Joy Hood of the EROS Data Center (EDC) from 1990-1992. He performed compositing using different vegetation index classifiers such as the normalized difference vegetation index (NDVI), the soil-adjusted vegetation index (SAVI), and a more recent modfied SAVI (MSAVI). The compositing routine also had modifications, including using information about expected vegetation phenological growth patterns, as well as using more than a single, maximum value. The NDVI classifier had the strongest fluctuations and instability and tended to select off-nadir forward scattering view angles. The other indices tested had better distributions of selected pixels and the use of more than a single, maximum, smoothed the temporal composited curves considerably. The results of this work will be presented at the PECORA 12 Symposium on "Land Information from Space-based Systems" sponsored by EROS Data Center on August 24-26, 1993, in Sioux Falls, South Dakota.

Future work in this area includes the use of more test sites with other biomes as well as implementing the atmosphere resistant

vegetation index (ARVI) and soil-atmosphere resistant vegetation index (SARVI) into the compositing scheme in order to minimize fluctuations attributed to the atmosphere.

## 3.   SEMINARS, VISITS, AND MEETINGS

**Presentation:**   "Development of vegetation and soil indices for MODIS-EOS",  by Huete, A.R., Justice, C., and Liu, H.  was presented at the 'Soils and Vegetation Remote Sensing' workshop held in Tempe, Arizona, January 6-8, 1993.

**Meeting:**   An informal presentation on the status of ASAS image analyses was made at the MONSOON 90' Meeting held in Santa Fe, New Mexico, April 26-27.

**Meeting:**    Wim van Leeuwen attended the Toulouse, France meeting regarding HAPEX-Sahel activities, May 11-13.  Wim gave a summary presentation on the ground radiometric data (Exotech and Spectron SE 590) that was collected.

**Lecture:**   3 days of lecture on remote sensing and global change, vegetation monitoring, soils assessment, and mixture modeling were presented at the Laboratory of Resources and Environment System (LREIS), within the Institute of Geography,  Chinese Academy of Sciences in Beijing, China, May 24-26, 1993.

**Seminar:**   "Vegetation indices: concepts and global applications" was presented at the Dept. of Forest Engineering at the Universidade Tecnica de Lisboa, Portugal on June 30, 1993.

## DATA/ ANALYSIS/ INTERPRETATION

The current status of the VI development includes atmospheric- and soil-derived calibration coefficients incorporated into the NDVI equation

for the reduction of percent error and vegetation equivalent noise.  Figure 1 depicts the progression and relationships among these VI's.  As can be seen, the improved versions of the NDVI equation attempt to either add a "soil" adjustment factor or normalize the atmosphere with use of the "blue band".  The ARVI and SARVI require prior correction for molecular scattering and gaseous absorption and hence normalizes the influence of aerosol scattering and absorption (Kaufman and Tanre, 1992).  The soil adjustment factor normalizes canopy background noises and make the VI more responsive to the vegetation (Huete, 1988).  The arrows further show how the 2 VI improvement paths can be linked to form equations that may adjust for both soil and atmospheric variations.
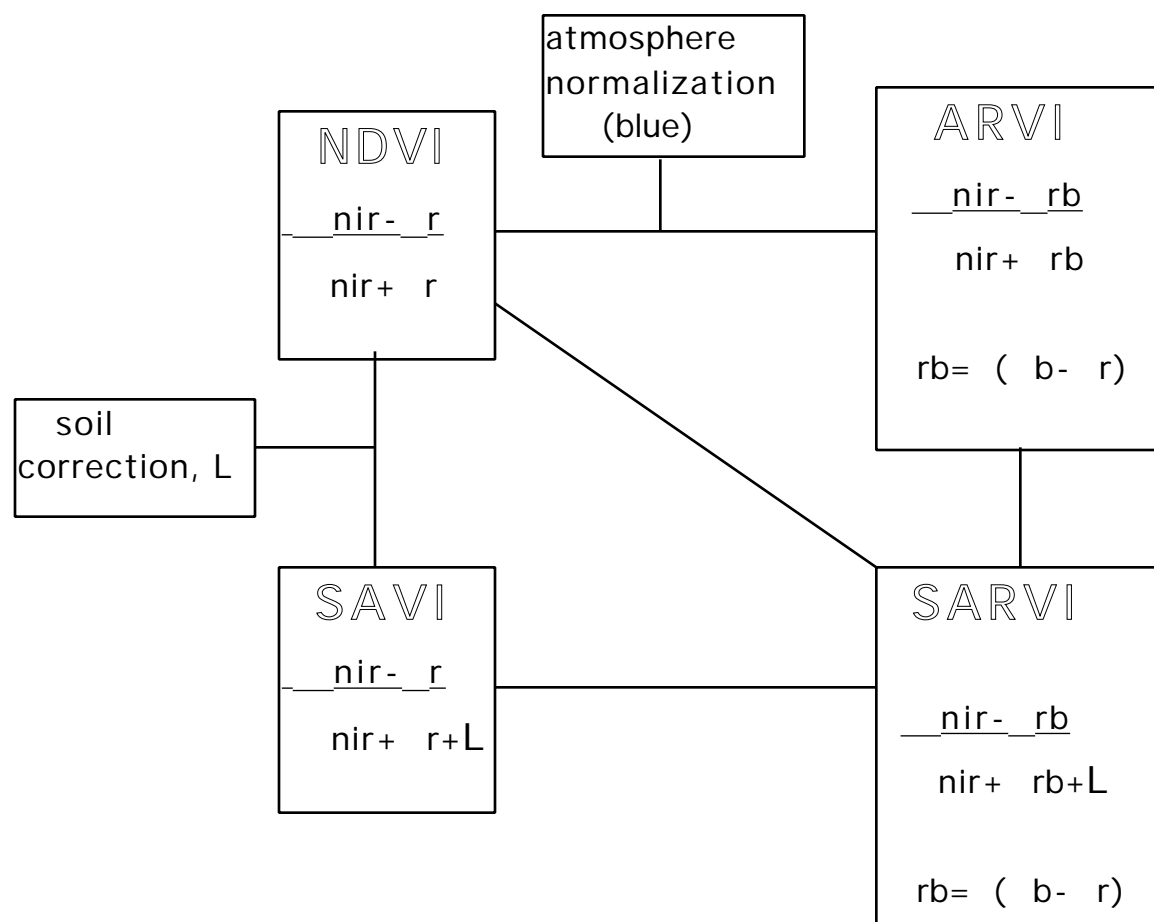


Figure1.    Relationship among the improved versions of the NDVI.

Recently, a sensitivity analyses was conducted to determine the extent of soil and atmosphere "noise" effects among these VI versions. An assessment was made on the coupling of these noises and feedback effects in correcting one form of noise without consideration for the other.  Another objective was to assess the impact of Rayleigh correction, as required by the ARVI and SARVI, on the noise and error terms.
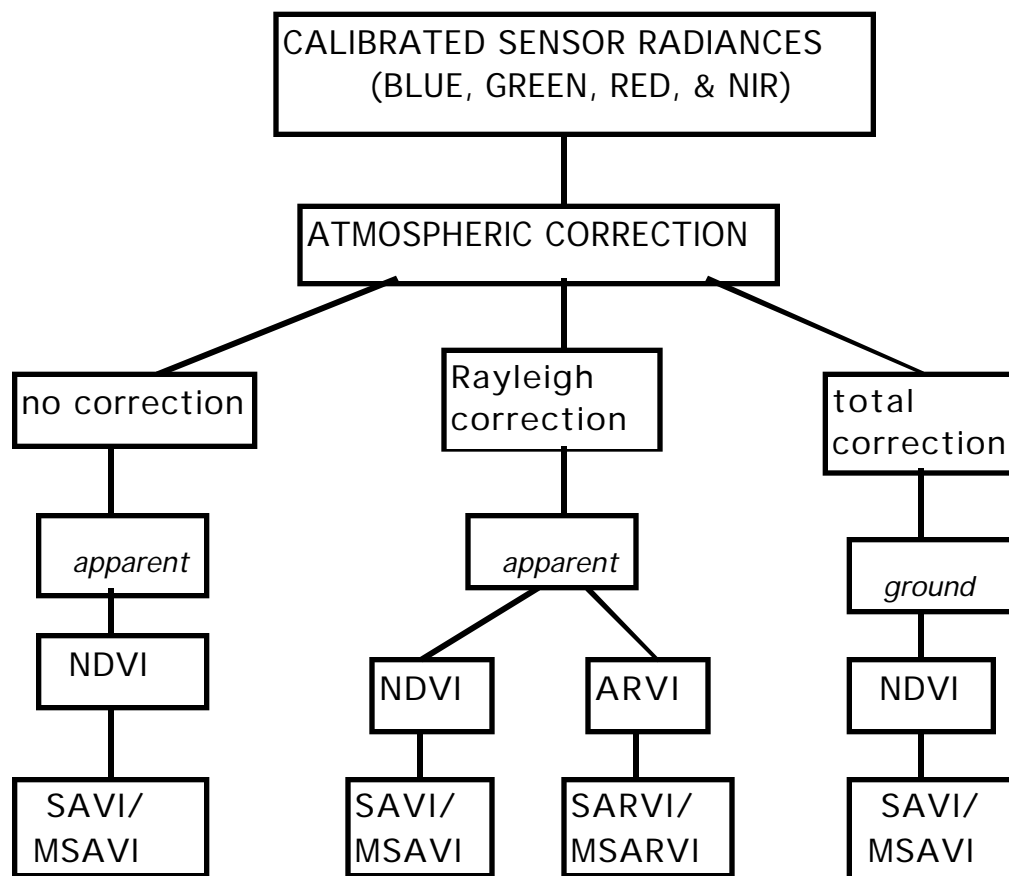


**Figure 2.**   Current status of MODIS vegetation index sensitivity analyses and processing scenario.

The modified SAVI (MSAVI) was also included in the analyses.  This uses an adjustable 'L' function, rather than the constant 0.5, to increase the dynamic range of the SAVI while further minimizing soil noise effects (Qi et. al., 1993).   Lastly, one could also add the adjustable L function into the SARVI equation and derive an MSARVI (Fig.2).   The sensitivity analyses was conducted on both measured data sets and SAIL model ouput simulations.  In general, the SARVI tends to have the best performance by minimizing both atmospheric and soil-induced variations.  The ARVI normalizes for atmosphere but has a large soil noise problem, more so than found with the NDVI.  When all error terms are considered, all new versions of the NDVI outperformed the NDVI.  A feedback problem, however, can be seen whereby the improvement of one form of noise aggravates or exaggerates another form of noise.

## ANTICIPATED FUTURE ACTION

1.   Attend the National Science Foundation's (NSF) "All Hands Meeting" in Estes Park, Colorado, September, 1993.  At this meeting scientists from NASA and NSF will jointly discuss satellite and ground-based approaches and measurements necessary for establishment of an effective land cover monitoring program.   Some discussion may be raised with respect to using the Chinese CERN sites in parallel with the LTER sites.

2. SCAR  EXPERIMENT:   there is  still interest in funding the "Smoke Clouds and Radiation (SCAR) experiment", which was prepared and submitted with Y. Kaufman as principal investigator and M. King, C. Justice, D. Tanre,  A. Huete, and others as co-investigators.  The goals of this project in Brazil may be delayed until 1995 and is described in the previous semi-annual report.  This will be done at the final stages of MODIS vegetation index evaluation and validation.  We were not able to participate in the East Coast pre-SCAR experiment, however, Chris Justice was able to participate for VI development.

3.  BOREAS:   the BOREAS proposal was submitted on behalf of the MODLAND team was submitted by Steve Running. A description of this project in northern Canada is also described in the previous semi-annual report.  There are no updates to report at this time.

4.  ISRAEL EXPERIMENT:  a proposal entitled "The effect of microphytic communities on satellite spectral reflectance in conjunction with climatic change studies of arid and semi-arid regions"  was submitted to the Ministry of Science and Technology, National Council for Research and Development (NCRD), Israel by Dr. Arnon Karnieli with myself as a co-PI. Dr. Karnieli is from the Ben-Gurion University of the Negev.  The purpose of this study is to determine the cause of the "desert artifact" areas which can be found in VI imagery (NOAA-AVHRR) throughout very arid regions, such as the Sahara.  Dr. Karnieli believes these artifacts may be caused by microphytic soil communities which absorb PAR for photosynthesis.  This serves as a good lower boundary condition for VI testing and noise assessment.

5. PECORA  12  SYMPOSIUM:   there are 3 paper/ presentations being prepared for the PECORA 12 Symposium on "Land Information from Space-based Systems" sponsored by EROS Data Center on August 24-26, 1993, in Sioux Falls, South Dakota.

  i.  Batchily, A.K., Huete, A.R., Moran, M.S., and Liu, H., Variation of vegetation indices derived from multi-temporal TM images at Walnut Gulch, Arizona.

  ii.  Qi, J., Huete, A.R., Hood, J., and Kerr, Y., On compositing of multitemporal data sets.

  iii.  van Leeuwen, W.J.D., Huete, A.R., and Liu, H., Evaluation of vegetation indices for retrieval of soil and vegetation parameters at HAPEX-II-Sahel.

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Qi, J., Chehbouni, A., Huete, A.R., and Kerr, Y.H., 1993,  A modified soil adjusted vegetation index, Remote Sens. Environ. (Accepted with minor revison, 6/93).

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Huete, A.R.,  Justice, C.O., and Liu, H.,  "Development of vegetation and soil indices for MODIS-EOS" , Remote Sens. Environ. (Submitted 1/93)

Qi, J., Huete, A.R., Moran, M.S., Chehbouni, A., and Jackson, R.D., 1993, Interpretation of vegetation indices derived from multi-temporal SPOT images,  Remote Sens. Environ., 44:89-101.

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Qi, J., Chehbouni, A., Huete, A.R., and Kerr, Y.H., 1993,  A modified soil adjusted vegetation index, Remote Sens. Environ. (Accepted with minor revison, 6/93).

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